DESIGN, ANALYSIS & FABRICATION OF A SCALED DOWN MODEL OF AN OPEN CHANNEL FLOW FLUME AND WEIR

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ABSTRACT

Thin plate weirs have been widely used for measuring discharge rate in open channel flow accurately. The flow characteristic over a thin plate weir is completely different between a single V notch weir and double VV notch weir. The continuity of the flow and accuracy of this type of weirs is reported to be poor. As an improvement, a compound weir composed of two triangle parts with a different notch angle and height has been designed. Mathematical method also been proposed to measure the discharge flow rate over the double VV notch compound weir. Height and width of weir plate are the two parameters characterizing discharge rate over the notch weirs. Mathematical calculation and simulation are conducted by measuring the discharge and the height over the weir for variable weir height and width.

ABSTRAK

Empangan plat nipis telah digunakan secara meluas bagi mengukur kadar pelepasan bendalir dalam aliran saluran terbuka dengan tepat. Ciri-ciri aliran melepasi empangan plat nipis adalah sama sekali berbeza diantara satu bentuk V dengan dua bentuk V. Kesinambungan aliran dan ketepatan jenis satu bentuk V ini adalah tidak tepat. Bagi menambahbaikkan nilai keputusan, satu empangan plat nipis berganda terdiri daripada dua bahagian segitiga dengan sudut kedudukan yang berbeza dan ketinggian yang berbeza telah direka. Kaedah matematik juga telah dicadangkan untuk mengukur kadar aliran melalui reka bentuk dua V pada empangan plat nipis. Ketinggian dan lebar plat adalah dua parameter yang merubah sifat kadar pelepasan air melalui empangan plat nipis. Pengiraan matematik dan simulasi dijalankan bagi mengukur kadar pelepasan air dan ketinggian paras melalui empangan plat nipis yang mempunyai nilai ketinggian dan lebar yang berbeza-beza.

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LIST OF SYMBOLS

A_C	Closed Area
A_0	Opening Area
C_d	Discharge Coefficient
g	Gravitational Acceleration
Q	Discharge Flow Rate
–	Degree

LIST OF ABBREVIATIONS

CFD	Computational Fluid Dynamics
ISO	International Organization for Standardization
STEP	Standard for the Exchange of Product Data
V	Single Notch/Single Triangular
VV	Double Notch/Double Triangular
3D	Three Dimensional

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

The world depends too much on the fossil fuel in order to generate energy such as electricity to power up gadgets and mechanical machines to use in daily life. An excessive usage of this source makes the fossil fuel deplete as it closer to extinction. In order to decrease the usage of fossil source, an alternative energy should be developed to replace fossil energy.

Tidal power nowadays has received world attention because of its high energy density, high predictability and low environmental impacts. The tidal power industry is expected to have a great potential in the future. Tidal energy current is more predictable, it is because tidal phenomena in the river acting everyday due to the moon rotations around the earth. The motions of the moon create a gravitational force that affects the low tide and high tide phenomena. Tidal wave creates the velocity in water flow and rotates the blades and rotor in the generator when the water flow through it, the rotation of generator will create electricity that can be used in daily life.

1.2 PROBLEM STATEMENT

Tidal wave energy or micro hydroelectric energy is an energy that has been produced from the kinetic energy of water flow into electricity by using the mechanical motion of rotor to generate electricity. Electricity produces from power plant only distributes into urban areas because of the population density and demanding of users is high in urban area compared to the rural area. In this case, rural citizens will have difficulties to obtain electricity for daily use. Micro hydro turbines will be the main option for rural citizens to produce electricity in a small scale. Micro hydro turbine is specially designed to work in a small river with low velocity of water flow. Before installing the micro hydro turbine in real river, we need to have an experiment on a micro hydro turbine to make sure it is fully functional. An open water channel flow flume needs to be design which it has the same flow characteristic as real river. Since UMP does not have a flume for experimental usage, we need to design and fabricate the flume channel that has flow characteristic exactly like real river. In order to create a flume that has a same characteristic as a river, a thin plate weir plays a main part to control the flow characteristic of water flow.

1.3 OBJECTIVES

The main objectives of this project are as follows:

(i) To analyze preliminary data obtained from the calculation and from analysis data source.

(ii) To evaluate the water discharge rate through VV notch thin plate weir.

(iii) To analyze and evaluate fluid behavior, flow characteristic and flow velocity at VV notch thin plate weir.

(iv) To develop an appropriate design of a scaled down model of $0.02m \times 0.02m$ VV notch thin plate weir.

1.4 SCOPE OF STUDY

There are several parameters in order to control this research flow. This means that the parameters in which the boundary of the research is focused on. Therefore, the scopes of this research are as follows:

(i) To design an appropriate VV notch thin plate weir.

(ii) To control a water discharge rate through the thin plate weir.

(iii) Simulate water characteristic such as backflow effect and flow velocity.

By applying this scope of project, the analysis can be done in order to get the best result of this research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a review of past research efforts related to open channel flow, flow measurement equation of thin plate weirs, discharge measurements and backflow effect. The review shows that the method being used and the results. The review also shows some recommendation so that the present research effort can be properly modified to get more accurate results based on previous study.

2.2 OPEN CHANNEL FLOW FLUME

Flume are the main devices used for flow measurement. They have the advantage that they require minimum head loss or fall which is an important consideration where the fall through the works is critical (Herschy 1995). Accurate flow measurement in open channel flow is very important in engineering applications. The structure used for open channel flow should be accurate, economical and easy to install, operate and maintenance. Open channel flow refers to the flow of liquid in channels open to the atmosphere or a partially filled conduit and is characterized by the presence of a liquid gas interface called the free surface (Cengel 2006). Open channel flow can be laminar or turbulent, and steady or unsteady, it also can be uniform with constant depth along the channel or non-uniform. Flow measuring structures are used for continuous measurement of discharges in open channels (Boiten W. 1993). Long-throated flumes and weirs provide a cost effective, practical and flexible tool for measuring discharge in open irrigation systems. A long throated flume or weir should have two main characteristics which are the flume should provide sufficient constriction to flow so that it is unaffected by the water level downstream of the structure, but not so much that the upstream water level becomes too high at maximum flow (chocking phenomena) and the upstream channel Froude number should be high enough to pass the sediment and low enough to produce a stable and a readable water surface at a gauging station. These criteria's are important to select the shape and size of a control cross section that results in desired flow conditions for the upstream channel (Bos et al. 1984). Open channel flows involve liquids whose densities are nearly constant, and thus the one dimensional steady flow conservation of mass equation is expressed as equation below.

$$\dot{V} = A_c V = \text{constant} \tag{2-1}$$

That is, the product of the flow cross section and the average flow velocity remains constant throughout the channel. Equation 2-1 between two sections along the channel is expressed as continuity equation below.

$$A_{C_1} V_1 = A_{C_2} V_2 \tag{2-2}$$

This continuity equation is identical to the steady flow conservation of mass equation for liquid flow in a pipe. Note that both the flow cross section and the average flow velocity may vary during flow but as stated, their product remains constant (Cengel 2010).

2.3 FLOW MEASUREMENT EQUATION OF THIN PLATE WEIRS

Among different types of weirs, thin plate weirs have been widely used for discharge measurements in open channel. The commonly used cross sections of thin plate weirs are rectangular and triangular. The use of compound thin plate weir having a combination of two triangular weirs with different notch angle has been studied to get an accuracy of flow measurements of discharge (Piratheepan et al. 2006). The discharge coefficient solely depends on the notch angle for fully developed flow and depends on many other parameters for partially developed flow (Piratheepan et al. 2006).

Henderson 1966, present an elementary analysis for discharge over a sharp-crested thin plate weir by assuming that the flow does not contract as it passes over the weir. By assuming that the pressure across the whole water column over the weir is atmospheric and the following equation was derived for discharge as shown below.

$$Q = \frac{8}{15} C_d \tan\frac{\theta}{2} \sqrt{2g}\, h^{\frac{5}{2}} \tag{2-3}$$

Where,

- Q = Discharge Rate, (m^3/s).
- C_d = Discharge Coefficient.
- g = Gravitational Acceleration, (m^2/s).
- θ = Notch angle.
- h = Head over The Weir,(m).

For V-notch weirs, C_d values mainly depended on the notch angle. The C_d values depend on the head, h only for low head values. For higher values of h, the C_d becomes constant since viscous and surface tension effects become negligible (Martinez et all. 2005). Many references from previous study show the similar curves for C_d value without providing the equation for it. So, curve fitting programs are used to obtain the following relationship for C_d which is related to notch angle of the weir. The equation is shown below (Martinez et al. 2005).

$$C_d = 0.6072 - 0.000874\theta + 6.1 \times 10^{-6}\theta^2 \tag{2-4}$$

Where θ = notch angle.

Piratheepan et al. (2006) were studied about discharge measurement in open channel using compound sharp-crested weirs. The authors the equation (1) from Henderson (1966) to predict the flow over the weir when head over the weir (h) is less than the lower weir height (h_0) and in this case, the discharge coefficient corresponding to lower notch is used. When the head over the weir is greater than h_0, four different methods are proposed to estimate the flow over the compound weirs.

Piratheepan Method 1 :

$$Q = \frac{8}{15} C_{d_2} \sqrt{2g} \tan\left(\frac{\theta_2}{2}\right)(h - h_0)^{\frac{5}{2}} + \frac{8}{15} C_{d_1} \sqrt{2g} \tan\left(\frac{\theta_1}{2}\right) h^{\frac{5}{2}} - \frac{8}{15} C_{d_1} \sqrt{2g} \tan\left(\frac{\theta_1}{2}\right)(h - h_0)^{\frac{5}{2}}$$

Piratheepan Method 2 :

$$Q = \frac{8}{15} C_{d_2} \sqrt{2g} \tan\left(\frac{\theta_2}{2}\right)(h - h_0 - x)^{\frac{5}{2}} + \frac{8}{15} C_{d_1} \sqrt{2g} \tan\left(\frac{\theta_1}{2}\right) h_0^{\frac{5}{2}} - \frac{8}{15} C_{d_2} \sqrt{2g} \tan\left(\frac{\theta_2}{2}\right) x^{\frac{5}{2}}$$

Piratheepan Method 3 :

$$Q = \frac{8}{15} C_{d_2} \sqrt{2g} \tan\left(\frac{\theta_2}{2}\right)(h - h_0)^{\frac{5}{2}} + \frac{8}{15} C_{d_1} \sqrt{2g} \tan\left(\frac{\theta_1}{2}\right) h^{\frac{5}{2}} - \frac{8}{15} C_{d_2} \sqrt{2g} \tan\left(\frac{\theta_2}{2}\right) x^{\frac{5}{2}}$$

Piratheepan Method 4 :

$$Q = \frac{8}{15} C_{d_2} \sqrt{2g} \tan\left(\frac{\theta_2}{2}\right)(h - h_0 x)^{\frac{5}{2}} + \frac{8}{15} C_{d_1} \sqrt{2g} \tan\left(\frac{\theta_1}{2}\right) h_0^{\frac{5}{2}} - \frac{8}{15} C_{d_1} \sqrt{2g} \tan\left(\frac{\theta_2}{2}\right) x^{\frac{5}{2}}$$

2.4 THIN PLATE WEIR

Thin plate weirs are commonly used as measuring devices in flumes and channels, enabling an accurate discharge measurement with simple instruments. The V-notch weirs, also called triangular weirs have an overflow edge in the form of an isosceles triangle. Thin plate weirs enable an accurate discharge measurement with simple instruments (Chanson

2012). A very steady discharge measurement technique is the volume per time method. The only rational method of calibrating weirs in accordance with hydrometric principles is the volumetric method, which depends on measuring the volume with a measuring reservoir and the time of flow (Troskolanski 1960).

Martinez et al. (2005) were studied about the design and calibration of a compound sharp crested weir. A weir is an overflow structure built perpendicular to an open channel axis to measure the discharge. There are mainly two types of weirs which is sharp crested weirs and broad crested weirs. In this study, the authors proposed a design and formulae to expressed discharge rate. The cross section of the proposed compound weir results from the composition of three single triangular weir areas. Therefore, the total discharge can be expressed as the sum of the discharges flowing over the overall opening area. Consequently, if the head, h is lower than the height of the lower part of the compound weir, h_0, it behaves as a single triangular weir with a notch angle θ_1. When the head is above the lower part of the weir ($h>h_0$), the flow can be obtained by the following equation.

$$Q=\frac{8}{15}C_{d_g}\sqrt{2g}\left[\tan\left(\frac{\theta_1}{2}\right)\left[h^{\frac{5}{2}}-\left(h-h_0\right)^{\frac{5}{2}}\right]+\tan\left(\frac{\theta_2}{2}\right)\left(h-h_0\right)^{\frac{5}{2}}\right] \tag{2-5}$$

The authors also derived a new single global discharge coefficient. The previous equation can be formulated as a function of a single global discharged coefficient. This equation relates the global discharge coefficient to the most significant variables that define the geometry of the weir. If the viscosity and surface tension effects are neglected, the discharge coefficient C_{d_1} and C_{d_2} are independent on the head and have a constant value for each notch angle. Such a simplification is acceptable for the upper section of the weir as h_0 is sufficiently high. The resulting global discharge coefficient is given by the following equation.

$$C_{d_g} = \frac{C_{d_1}\left(\frac{{}_{1}}{2}\right)\bullet\left[\frac{1}{\left(1-\frac{h_0}{h}\right)^{\frac{5}{2}}}-1\right]+C_{d_2}\,\tan\left(\frac{{}_{2}}{2}\right)}{\tan\left(\frac{{}_{1}}{2}\right)\bullet\left[\frac{1}{\left(1-\frac{h_0}{h}\right)^{\frac{5}{2}}}-1\right]+\tan\left(\frac{{}_{1}}{2}\right)}$$

.(2-6)

2.5 BACKFLOW EFFECT.

Triangular weir with a small notch angle is found to be accurate in discharge measurements however, it can be only be used to measure small discharges. When measuring high discharges by using the single thin plate weirs, backwater effects might affect the structures located upstream of the weir (Piratheepan et al. 2006).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter presents the overall methodology of this project. Project starts off with planning by using a flow chart as shown in Figure 3.1 acts as a guide to successfully carry out the case study step by step.

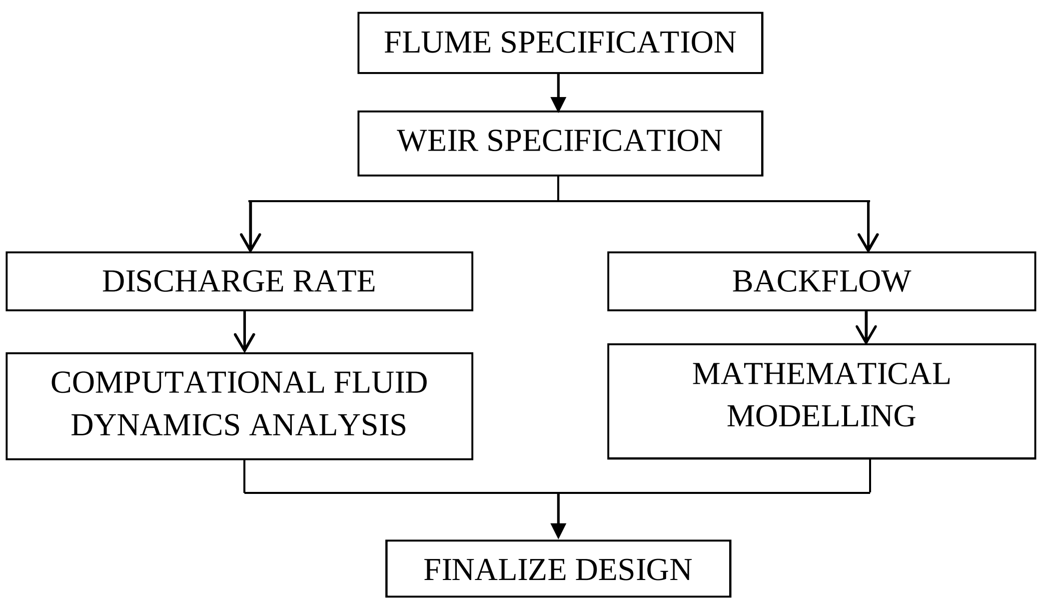

Figure 3.1: Flow Chart.

3.2 FLUME SPECIFICATION

The flume is primary devices for measuring flow of water in open channels. There are few conditions we need to consider before designing on flume and weir which is to maintain the water depth in the flume and to control the flow rate so the inlet flow rate must be equal to outlet flow rate as follow the conservation of mass and energy equations shows in equation 2-1. A flume design of scaled down by 1:10 given the flume specification of 0.2 meter width and 0.2 meter height and 3 meter length showed in Figure 3.2. The aim of this study is to achieve at least a minimum steady flow velocity of 1 m/s in the flume test section. According to equation 2-1, since the cross sectional area of the flume is 0.04 m^2 and the flow velocity need to achieve is 1 m/s, so the volume flow rate need to obtain in the flume test section area is 0.04 m^3/s. Since the continuity equation 2-2 show that the volume flow rate inlet must be equal to volume flow rate outlet, 0.04 m^3/s of discharge rate must be achieved at the weir outlet.

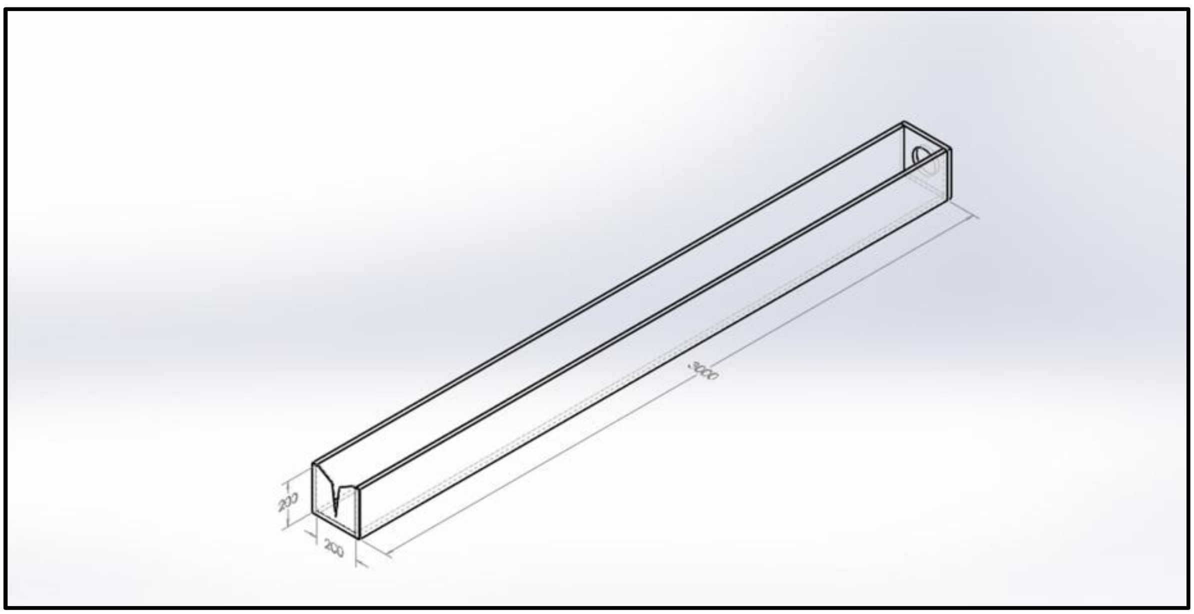

Figure 3.2 : Flume Test Section Dimension

3.3 WEIR SPECIFICATION

The VV notch thin plate weir was designed in 3D design using SolidWorks software. Figure 3.3 shows the 3D design of VV Notch Thin Plate Weir. Based on the objectives, the main part that needs to be focus is the opening area where the water goes through after it. Opening area, A_o of the weir will affect the discharge rate, Q while closed area, A_c will affect the backflow phenomena.

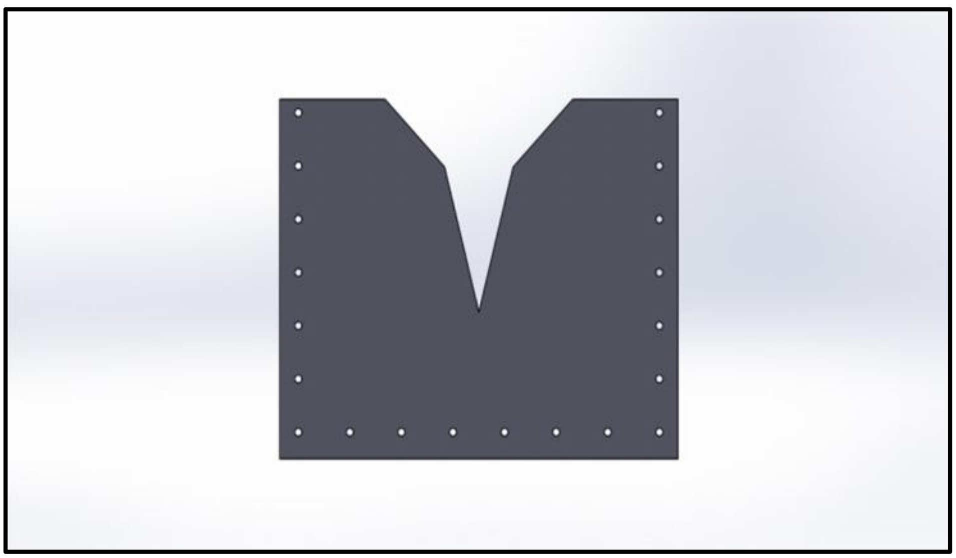

Figure 3.3 : Concept Design of VV Notch Thin Plate Weir Scaled Down Model

Design of VV Notch Thin Plate Weir must follow the tolerances in construction of thin plate weirs are given in the ISO standard but the most important considerations in the design and construction of thin plate weirs are as follows :

i. The structure should be rigid and watertight.
ii. The crest edges should be machined to a 90° angle should not be rounded and should be free of burrs.
iii. The water nappe should be at atmospheric pressure and ventilated.

iv. The water to be gauged should be free of debris which could damage the crest or settle in the approach channel.

v. The crest should not be painted as a means of preventing rust or pitting. A badly rounded or damaged crest should be replaced.

A VV notch thin plate weir are consist of two compound V notch weir, weir 1 which is lower weir and weir 2, upper weir. All the possible design of VV Notch Thin Plate weirs is based on choosing parameters and geometry as shown in Figure 3.4 below.

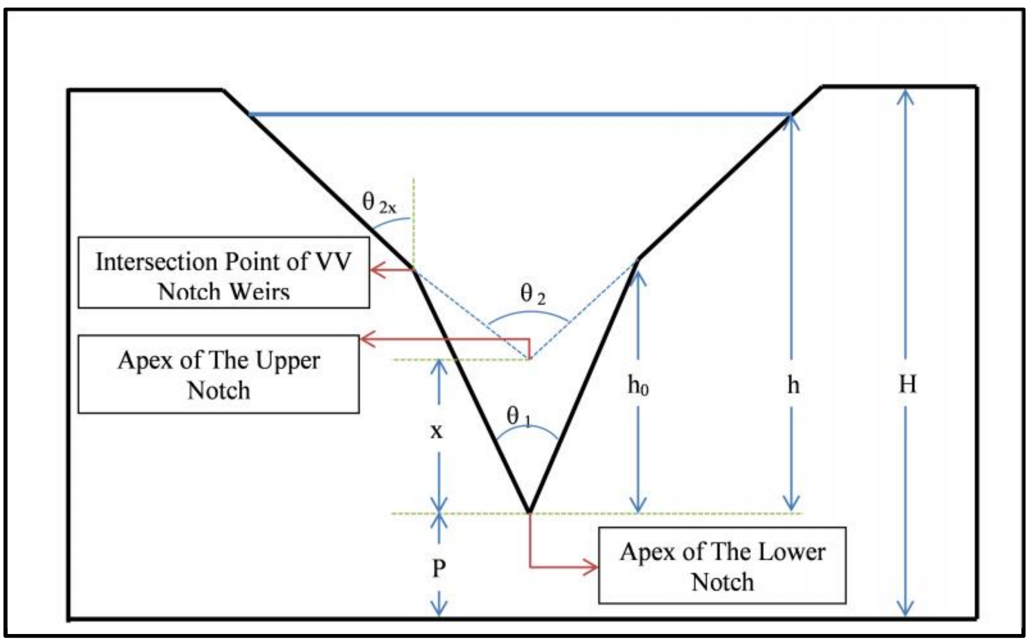

Figure 3.4 : Parameters Considered for VV Notch Thin Plate Weir

In order to design an acceptable weir, there are few limits and qualification to follow.

i. Distance between the apex of lower notch and level of water,h should not be less than 0.02m.

ii. Distance between bottom of the flame of lower notch, p should not be less than 0.02m.

iii. Angle of upper notch, θ_2 should be higher than angle of lower notch, θ_1.

iv. Water level must be higher than intersection point of VV notch weirs.

v. Distance between two notches, x should be higher than 0.02m.

All 662 possible designs of VV Notch Thin Plate weirs were tabulated on a table of Possible Design Data. All the possible design is named based on parameters chosen. The names are based on head, H and the angle of the notch opening, θ for lower notch and upper notch. Upper and lower weir have been chosen as shown in Figure 3.5 & Figure 3.6 below.

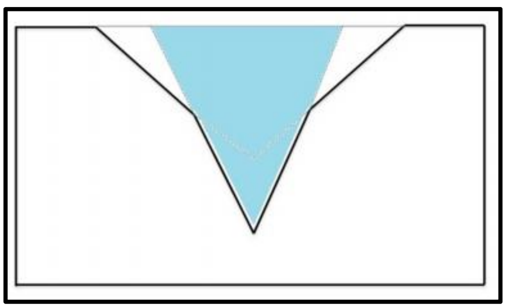

Figure 3.5 : Lower Weir

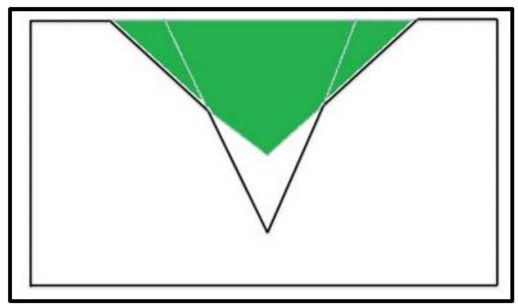

Figure 3.6 : Upper Weir

Each possible design is given their coding name based on parameters variable chosen. The parameters variable chosen is the head, h and angle of opening notch, θ of each lower and upper weir. The example of coding name is shown below.

H180D15 ***H160D22.5***

Parameter of Lower Weir

Parameter of Upper

Let,

H = Head of weir.

D = Angle of notch opening.

3.4 DISCHARGE RATE

All 662 possible design was then arranged in ascending of opening area. The graph of opening area against type of weir were plotted in Figure 3.7. the first group of ten sample design are selected and the mean value of opening area in those group of sample are chosen for the first selected design. This method were repeated until we achieve 62 design of compound VV notch thin plate weir. Graph of 62 possible design in changing of opening area and discharge rate for were plotted to see the pattern of graph. Discharge rate was calculated using five different methods as a benchmark in order to compare with the new derivation method. Graph of 62 designs was plotted below in Figure 3.7